FAST DIRECTIONAL FRACTAL CODING OF SUBBANDS USING DECISION-DIRECTED CLUSTERING FOR BLOCK CLASSIFICATION

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ABSTRACT

We propose a new image compression scheme based on fractal coding of a wavelet transform coefficients using a fast non-iterative algorithm for the codebook generation. The original image is first decomposed into subbands containing information in different spatial directions and different scales, using an orthogonal wavelet filter bank. Subbands are encoded using Local Iterated Function Systems (LIFS) with range and domain blocks presenting horizontal or vertical directionalities. Their sizes are estimated according to the correlation lengths and resolution of each subband. The computational complexity is greatly decreased by using subband decomposition. In addition a fast non-iterative algorithm is implemented for the blocks classification. This algorithm creates progressively the codebook during only one scanning of the training set. We proves the efficiency of the proposed approach both in terms of PSNR/bit rate and computation time.

1. INTRODUCTION

Fractal image compression using self-similarity has recently drawn considerable attention since the Iterated Function System (IFS) was proposed by Barnsley [1]. The first automated fractal coding algorithm based on Local Iterated Function Systems (LIFS) was developed by Jacquin [2]. This approach using self-affine transformations leads to very encouraging results at low bit rates [3],[4].

The fractal encoding process is very time consuming. This limits its use in the applications which impose the time constraint. A solution to this problem consists to limit the self-similarity search to a reduced neighborhood of the range block. Unfortunately the choice of this local domain block set is arbitrary and decreases the decompressed image quality. Recent studies propose a block clustering process of domain blocks in order to accelerate the LIFS generation. In [5] and [10], LBG algorithm is used for block classification. In [5], the cluster centroids are adapted to the range blocks. The initialization phase is rather slow because of this adaptability and the use of LBG algorithm. In [6], the

block clustering is done by self-organizing maps [7]. Wein et *al.*[8] have proposed a clustering process on image domain blocks where the clusters are formed with K-d trees and the fast Pairwise Nearest Neighbor (PNN) algorithm [9]. It is clear that the quality of the reconstructed images decreases with block clustering. We have to find a trade-off between the computation time, the number of classes and the image quality for a given bit rate.

Another drawback of LIFS in the spatial domain is the blocking effect which appears at low bit rates whatever the partition used (square, rectangular [3] or triangular [10]).

In this study we propose the Fast Directional Fractal Coding of Subbands (FDFCS) which uses a fast non-iterative algorithm for codebook generation in order to :

- reduce the computation time with a subband/fractal hybrid approach [11] (Figure.1 and section 2) and a clustering process on subband domain blocks with clusters progressively created during only one scanning of the training set (section 3).
- limit the blocking effects on the reconstructed images by partitioning a wavelet transform domain [12] instead of the spatial domain.
- take advantage of the "natural classification" obtained using a subband decomposition [13], which leads to small number of directional clusters.

2. ADAPTIVE PARTITION AND FRACTAL CODING OF SUBBANDS (FCS)

The sizes of range blocks R_i and domain blocks D_j are estimated by computing the correlation length of both raws $C_i(k)$ and columns $C_j(k)$ in each subband in order to take into account the directionality [14].

Figure. 1 shows the size of the range blocks adapted to the directionality and to the resolution of the "Building" image.
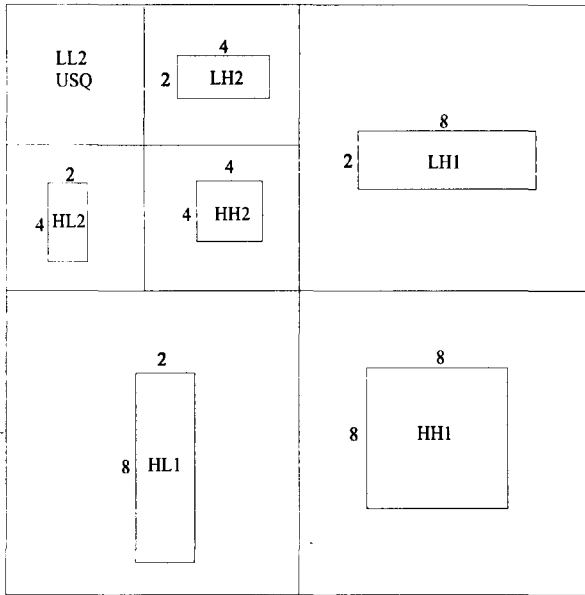
Figure. 1: Octave decomposition of an image until resolution 2^{-2}. LLi, LHi, HLi, HHi, are the low frequency, the horizontal high frequency, the vertical high frequency and the angular high frequency subbands at resolution 2^{-i}. A Uniform Scalar Quantizer (USQ) is applied on LL2.

Given a total bit budget, the subband bit rate and the number of decompositions are determined using an algorithm similar to the one proposed by Ramchandran et al. [15]. This algorithm selects the optimal bit allocation and the best decomposition number in order to minimize the overall mean square error under the constraint of a total number of coding bit lower than a coding bit budget.

Table.1 gives PSNR/bit per pixel results associated to the whole coding scheme (FCS with adaptive partition + Full search) for "Peppers" and "Building" images.

3. FRACTAL COMPRESSION OF SUBBAND USING CLUSTERING

The subband/fractal hybrid approach leads to a 12:1 gain in computation time [11]. In addition, we implement a block clustering technique in each subband.

The idea is to divide the set of domain blocks into clusters, each cluster having a representative block. We assume that a distance between any two domain blocks within a cluster is small. For a given range block, the search for a matching domain block is done in two steps. At the first step, the best cluster is located by minimizing the distance between the range block and the cluster controid. At the second step, the best domain block within the cluster is located.

We suppose, that we have C cluster, N range blocks R_i, M domain blocks D_j. For simplicity we assume that the codebook clusters are uniformly distributed, then the encoding involves $NC + N\frac{M}{C}$ comparisons (distance calculations). The computation time is minimized by taking $C = \sqrt{M}$, each cluster containing $\sqrt{M}$ blocks.

α-PROGRESSIVE CONSTRUCTIVE CLUSTERING ALGORITHM (PCC)

The idea here consists of creating the codewords progressively, during only one scanning of the training set [16]. At the beginning, the codebook is initialized by the first vector v_1 found in the training set; then each input vector v_m is mapped into the nearest neighbor codeword w_i, which minimizes the distortion error (the squared error is used here), expressed as $E = d(w_i, v_m)$. This error is then compared with a pre-defined threshold Th, and two cases are considered (see Figure.2):

1. $E \leq Th$: in this case, v_m belongs to the cluster w_i and its centroid is adjusted to take v_m into consideration.

2. $E > Th$: this means that v_m does not belong to the cluster w_i; the new codeword v_m is added to the codebook if its size is not yet out of range. If this codebook size is reached, v_m is associated to the nearest cluster.

v_s = new vector to classify
w_i = cluster centroid
w_i^* = adjusted cluster centroid
w_3 = new cluster centroid
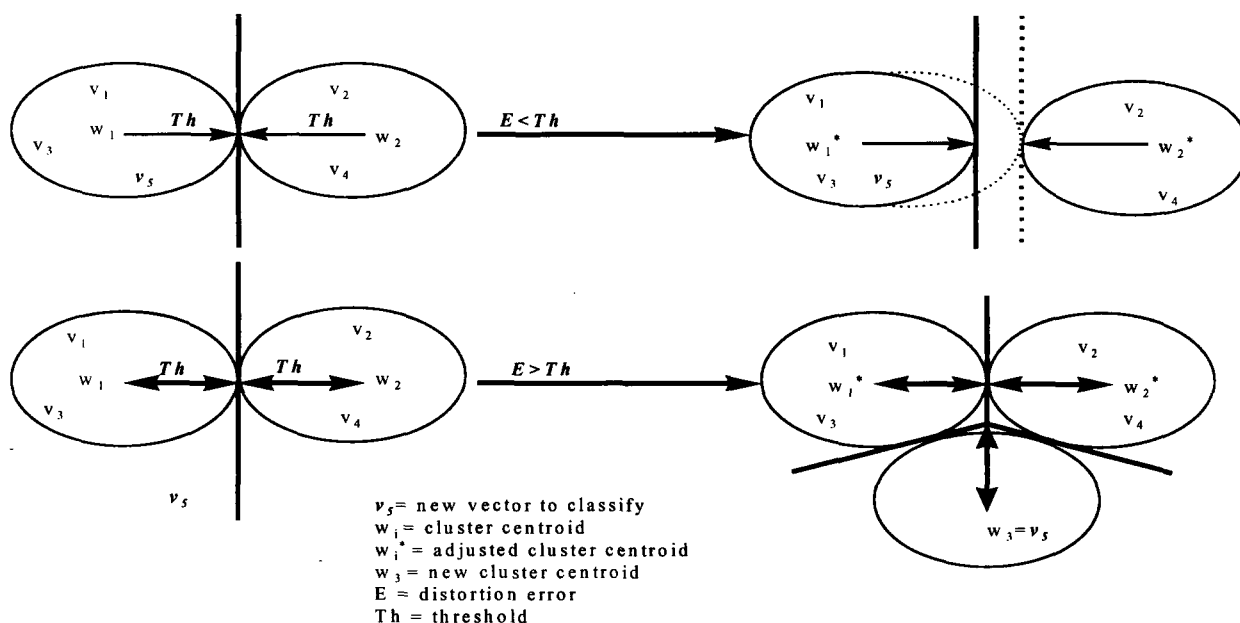E = distortion error
Th = threshold

Figure. 2: The Progressive Constructive Clustering (PCC) algorithm

b-DECISION DIRECTED CLUSTERING ALGORITHM (DDC)

The PCC algorithm presented in the previous section has been modified to introduce a *guard zone*, as proposed in the Decision-Directed Clustering (DDC) algorithm [16].

Similarly, as seen in the PCC algorithm, the codebook is initialized by the first vector v_1 found in the training set, then each input vector v_m is mapped into the nearest neighbor codeword w_j, which minimizes the distortion error E.

For a certain predetermined threshold A; $E \leq A$, v_m belongs to the cluster w_j and its centroid is adjusted to take v_m into consideration. All other centroids are unchanged.

Now if, for a certain $B > A$; $E \geq B$, that means v_m does not belong to the cluster w_j, we decide that a new cluster is generated which consists of v_m only and the number of clusters is increased by one.

The new codeword v_m is added to the codebook if its size is not yet out of range; If this codebook size is reached, v_m is associated to the nearest cluster.

$E = A$ and $E = B$ defines hyperellipsoids. The region between the two hyperellipsoids is called the *guard zone*. If v_m falls into the guard zone, $A < E < B$, it is temporarily stored and tagged for later processing. This approach avoiding the creation of unnecessary clusters, is called "*guard zone*" and is illustrated on Figure.3.
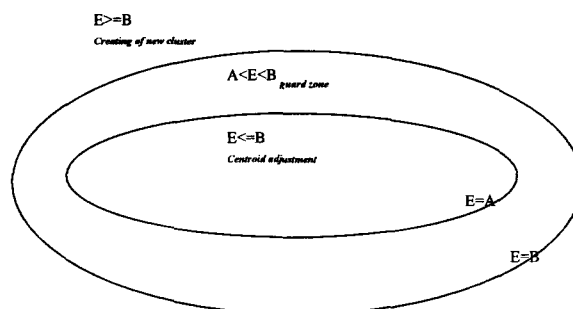

Figure. 3: The Decision-directed Clustering (DDC) algorithm

In our case, after creating all the codewords, during only one scanning of the training set, we come back to the guard zone, calculate the associated codeword of each guard zone vector and the codebook is adjusted to take this zone into consideration.

4. RESULTS

The DDC algorithm has been implemented. Table 1 shows, for a global bit rate of 0.8 bpp, the improvement in computational time on "Peppers" and "Building" in addition to the algorithms discussed in section 3. Our approach leads to a gain of 50:1 factor comparing to the fractal coding of the full resolution image. The encoding process is about 20 seconds on a Silicon Graphics Indigo2. Considering these results, this fractal image compression technique appears as a potential candidate for time constraint applications such as satellite and medical imaging [17].

for 0.8 bpp	Peppers			Building		
	PSNR(dB)	Time (sec)	Gain	PSNR(dB)	Time (sec)	Gain
Full search on the original image	32.10	974	T	29.7	1461	T
Clustering on the original image	30.31	79	T/12.3	28.8	86	T/17
Quadrant Variance classification (Fisher)	31.38	76	T/12.9	29.6	96	T/12.9
FCS with adaptive partition	32.42	56	T/17.3	35.0	108	T/13.5
FCS with adaptive partition and clustering	31.48	20	T/48	33.4	28	T/54.7

Table 1: The decompressed image quality comparing FCS (Full search or Clustering) and Fisher algorithm (quadrant variance classification) in term of real speedup and PSNR.

Table 1 also shows that the quality of the reconstructed images are better than those obtained by using the clustering on the full resolution image. The proposed approach results in a significant improvement comparing to Fisher [3] variance classification algorithm in terms of PSNR. Remark that the PSNR slightly decreases with clustering because of the choice of the best cluster for a range block. Indeed by minimizing the distance between the range block and a representative block of one cluster, we are not sure to find the optimal domain block in this cluster. However the PSNR remains higher or almost equivalent to the other algorithms considered in Table 1.

6. CONCLUSION

A new image compression scheme based on Fractal Coding of Subbands (FCS) is proposed. Subbands are encoded using Local Iterated Function Systems (LIFS) with range and domain blocks presenting horizontal or vertical directionalities. The computational complexity of the fractal compression algorithm is reduced by about 12 :1 factor when generating LIFS for subbands of lower resolutions instead of for a full resolution image. In addition, a fast non-iterative algorithm for codebook generation is implemented to accelerate the LIFS generation in each subband. FCS using this clustering technique leads to a 50:1 gain in computational time comparing to fractal coding of a full resolution image. In terms of PSNR/bit rate, the proposed hybrid coding scheme improves the quality of the reconstructed images comparing to the quality obtained with other fractal coding techniques.

7. REFERENCES

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